Structural Design of High-Rise Buildings for Wind Loads

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Summary

Estimates of wind-induced wind effects on tall buildings are based largely on 1970s and 1980s technology, and can vary by more than 40 % depending upon the wind engineering laboratory. We describe a time-domain procedure allowing the realistic estimation of wind-induced demand-to-capacity ratios with any mean recurrence interval in any individual member, through: (a) the development of micrometeorological, aerodynamics, and wind climatological data, (b) the use of a physically and probabilistically realistic aerodynamic/climatological interfacing model, and (c) the use of modern computational resources for the significant improvement of the quality of the design through differentiated structural methods employing influence coefficients specific to each member. The paper then addresses the increase in load factors associated with uncertainties in the parameters that determine wind effects and, in particular, in the natural frequencies and damping ratios.

Keywords: Building technology; damping; dynamic response; extreme wind climatology; high-rise buildings; micrometeorology; natural frequencies; wind directionality; wind engineering; World Trade Center towers.

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Methods for estimating wind-induced effects on rigid buildings are fairly well established. This is true to a much lesser extent of tall, flexible buildings. For this reason estimates of wind effects obtained for the same building by different wind engineering laboratories can differ significantly. For example, as reported by a National Institute of Standards and Technology (NIST) investigation, estimates by two wind engineering laboratories of wind-induced base moments in the World Trade Center towers differed by over 40 %. This discrepancy was due to differences in the respective models of (a) the extreme wind speeds, (b) the joint directional effects of the aerodynamics and extreme wind velocities, (c) blockage effects, and (d) the wind speed variation with height above ground. These four modeling areas need to be addressed in standards of practice, and efforts are currently being made within the framework of the ASCE Standard 7 Task Committee on Wind Loads to improve upon the current state of affairs. In view of such differences, to avoid designing structures on the basis of possibly inadequate estimates of wind effects, some structural engineers have a policy of commissioning two independent wind engineering reports.

Full access to the reports issued by the two laboratories allowed the NIST investigation to scrutinize current practices in detail. Such scrutiny is unusual, since wind engineering reports are typically confidential, even though they entail safety issues of major public interest. In addition to the discrepancies mentioned earlier, the lack of transparency of the reports was noted both by the NIST investigators and the independent consultants tasked with reviewing the investigators' work; that is, the reports or parts thereof were perceived as difficult or impossible to understand or check even by structural engineers well versed in wind engineering [1].

This paper decribes a clear, transparent, and effective time-domain procedure which requires that the following data be provided to the structural engineer by the wind engineering consultant: (1) aerodynamic pressures measured synchronously in wind tunnel tests at a large number of pressure taps on the building envelope and for a sufficient number of wind directions; (2) directional wind speed data obtained from climatological data and attendant simulations, and (3) the ratio, measured in the wind tunnel for each wind direction, between wind speeds at 10 m elevation in open terrain and the corresponding mean hourly wind speeds at the top of the building. Once these data are made available by the consultant, structural engineers can use them on their own for routine calculations of the dynamic building response to wind. In particular, in conjunction with the appropriate influence coefficients, the engineers can use those data in a rigorous manner from a structural engineering point of view to estimate the internal forces and demand-to-capacity ratios for any individual member, just as structural engineers do for buildings subjected to seismic loads.

We first explain the basic features of the procedure, and its use when uncertainties pertaining to the factors that determine the wind loading are not explicitly taken into account. This case is applicable to the estimation of wind effects corresponding to a basic mean recurrence interval (MRI) associated with Allowable Stress Design (ASD), or to a larger MRI that implicitly accounts for those uncertainties and is used for Strength Design (SD). Next we address issues associated with accounting explicitly for uncertainties in the parameters that determine the wind effects. Unlike for routine structures, for which simplifications inherent in standard provisions are acceptable, for tall buildings these issues need to be considered with care, since oversimplified estimates of the response would defeat the purpose of ad-hoc wind tunnel testing and of estimating climatological, aerodynamics, and dynamics directionality effects. An application of the procedure is then presented, which shows that, for the SD of tall buildings to assure an adequate safety level, it is in general necessary to account for uncertainties in the damping and the natural frequencies of vibration, which play no role in the design of rigid buildings.

It is assumed throughout that the building does not exhibit significant aeroelastic effects, an assumption that is currently also made for buildings designed on the basis wind tunnel tests that use the High-Frequency Force Balance (HFFB) technique.

[1] *Federal Building and Fire Safety Investigation of the World Trade Center Disaster*, NIST NCSTAR 1-2A, Table 4-4, National Institute of Standards and Technology, Gaithersburg, MD, 2005 (http://wtc.nist.gov/NISTNCSTAR1-2.pdf).